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A fast surrogate model tailor-made for real time control

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Keywords

Surrogate models, piecewise linear, volume-discharge relationships, real time control, input models.

Biography

Morten Borup is assistant professor at DTU Environment. His main research areas are modelling of urban water systems, real time models and data assimilation.

Summary

A surrogate model of a detailed hydraulic urban drainage model is created for supplying inflow forecasts to an MPC model for 31 separate locations. The original model is subdivided into 66 compartments in-between which the flows are modelled using piecewise linear volume-discharge relationships extracted from the original model. The surrogate model is 9000 times faster than the original model, with just a minor deviation from the original model results.

Introduction

The current work is part of a project in which a Model Predictive Control (MPC) system is created with the drainage system of the city of Aarhus (Denmark) as the first. All parts of the system that are directly influenced by control decisions are modelled with an “internal MPC model”, which needs forecasts of inflows at all nodes interfacing with upstream parts of the system for the entire control horizon, as well as a valid uncertainty description for the forecasts. This is to be provided as ensembles of flow forecasts produced by an “input model”. New ensembles of forecasts up to 2 hours ahead need to be produced every 5 minutes, which means that the input models should be computationally cheap. It makes a difference for the MPC scheme where the individual inflows enter the part of the system that is controlled by the MPC. Therefore the input models should be capable of simulating the inflow in each individual pipe that leads to the MPC part. The utility continuously updates the detailed hydraulic models of their system to reflect the most current conditions. These models could in theory provide all the required inputs for the MPC but are too computationally expensive for online operation. This work describes a newly developed surrogate model (SM) that emulates the response of detailed hydraulic models sufficiently well in a computationally very efficient way.

Method

The surrogate model is constructed by subdividing a detailed model into a number of smaller compartments in-between which the flows are computed using tabulated, piecewise linear volume-discharge (VQ) relationships derived from the results of model runs with the detailed model. This overall principle has been used by Thrysøe et al (2016) to produce flood models suitable for planning

purposes. Where the main focus of the flood models is to estimate the volume of water discharged to the surface, the requirements to an MPC input model used for controlling the underground drainage system are somewhat different. First of all, flows to the surface are not of importance and therefore not included in the model. The timing of the flows is, however, of large importance for the MPC scheme as well as for a later combination with a data assimilation scheme (Borup et al., 2013). Therefore timing, including dynamics caused by backwater in the pipes, needs to be taken explicitly into account when subdividing the detailed model into SM compartments.

The requirement for the specific SM model is to compute the inflow to the internal MPC model at 31 specific input locations, see Figure 1 left. The 66 compartments of the SM model are visualized in Figure 1 right.

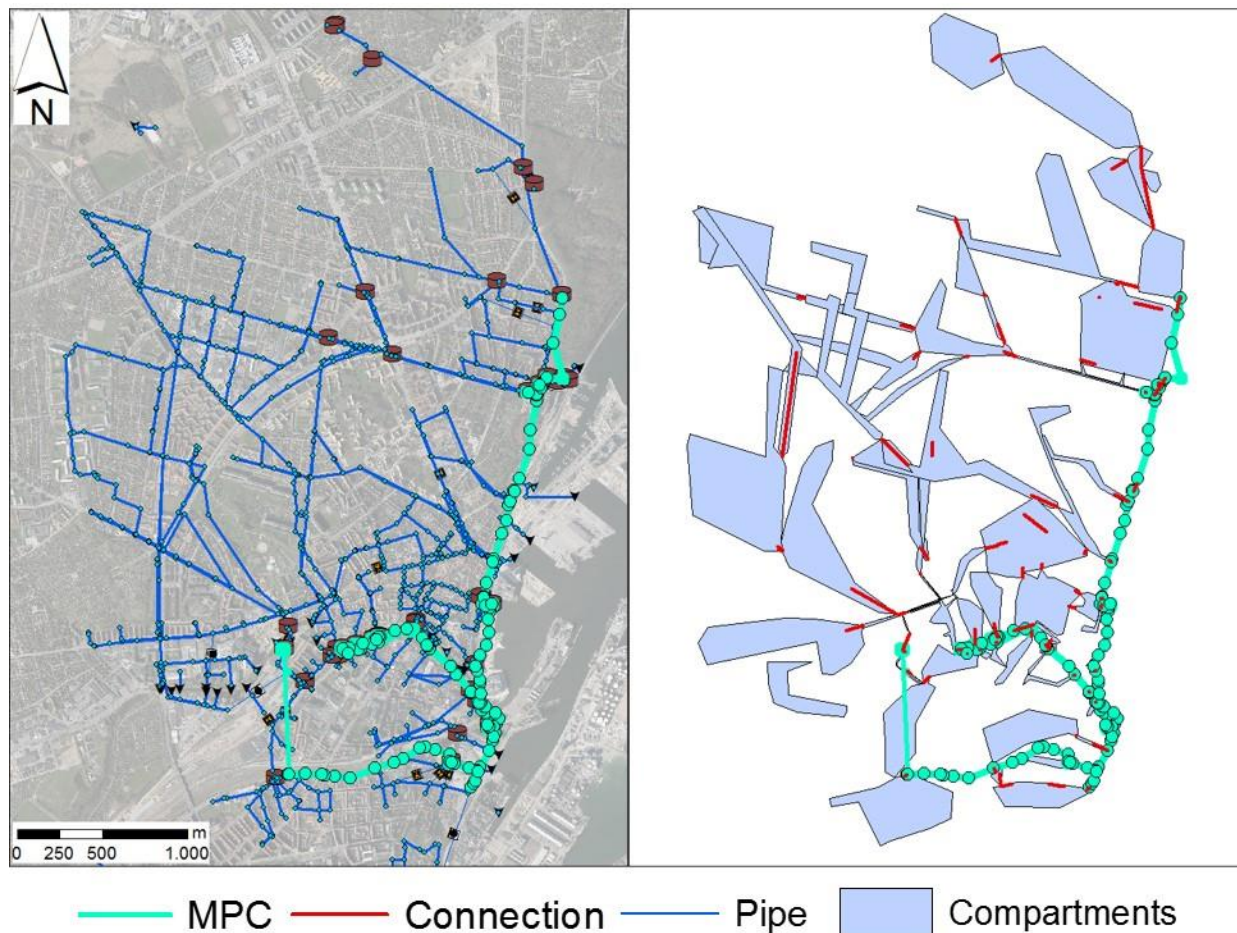


Figure 1: (left) Detailed hydraulic model with the MPC part highlighted. (Right) The 66 compartments of the SM model and connections out of each compartment.

Weirs and obvious flow constrains are always chosen as compartment boundaries. Furthermore, places of special importance for the dynamics are located by investigating the level of dispersion in depth-discharge relationships in the individual links in the detailed model. The hydrograph out of the most

upstream compartments will always be smoothened out to an extent where peaks are not well represented. Therefore it is sought to always have two or more compartments upstream of particular important junctions and outlets.

The V-Q parameters for all connections out of each SM compartment are extracted from model results obtained when propagating a long rain, which has intensities increasing in minor steps, through the detailed model.

Since computational speed is the prime motivation for creating the surrogate models, an efficient computational engine was coded in C#. This engine with a small tutorial on how to use it from MATLAB can be found on (to be announced later).

Results and Discussions

To quantify the performance a 14 days validation period with a variety of rainfall events with different relevant properties were used. Two measures of performance are shown in Figure 2: ‘relVol’ is the accumulated discharge for the validation period for the SM model relative to the detailed model, and NSE30 is the Nash-Sutcliffe efficiency index between the detailed and the SM model after applying a 30 minute moving average to both time series. This moving average is applied to be able to use the same efficiency index for both rapidly changing connections, such as weirs, as links with slow changing flows.

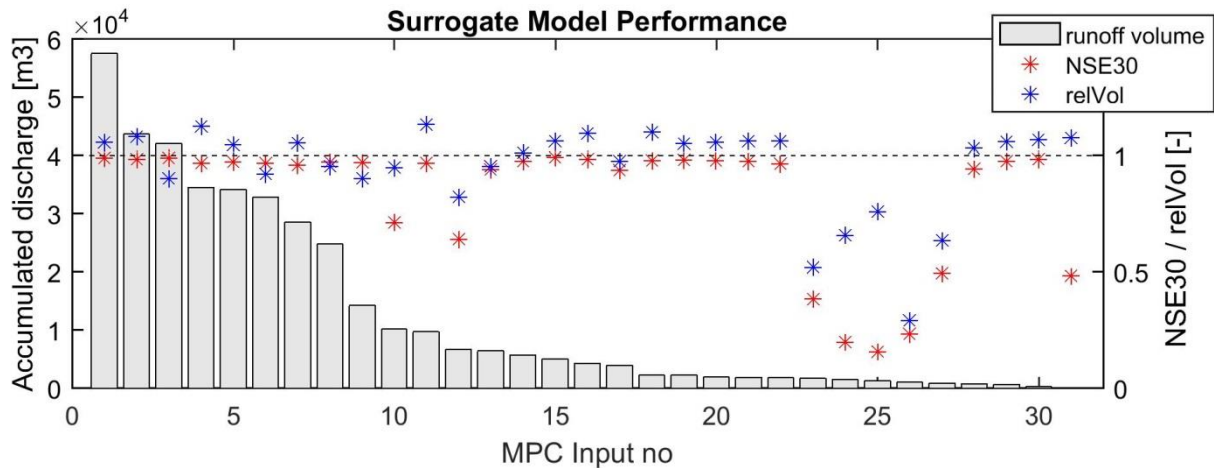


Figure 2: Performance of the SM model for the 31 links connecting the SM with the internal MPC model. The input links has been sorted according to the accumulated discharge.

Figure 2 shows that the 9 most significant inflows to the internal MPC model have both relVol and NSE30 close to 1, which shows good performance considering both volume and timing of peaks. Some of the less significant inflows perform worse, primarily due to backwater from the MPC part of the model that cannot be taken into account by the SM model.

The computation time for the detailed model was two hours and three minutes while the SM model runs the same period in 0.8 s. This is a speedup of a factor of 9000.

Conclusions

Our surrogate model is based on a detailed hydraulic model and can thus easily be modified as the detailed model is modified to reflect changes in the sewer catchment. It is 9000 times faster than the original detailed model and it is sufficiently accurate to be used as input model for the MPC scheme.

Acknowledgments

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